North American Journal of Fisheries Management 17:719–725, 1997

Estimation of Population Density of Largemouth Bass in Ponds by Using Mark–Recapture and Electrofishing Catch per Effort

C. MICHAEL EDWARDS, RAY W. DRENNER,[1] KIRSTEN L. GALLO, AND KERRI E. RIEGER

Biology Department, Texas Christian University
Fort Worth, Texas 76129, USA

Abstract.—Populations of largemouth bass *Micropterus salmoides* longer than 199 mm total length (TL) in hatchery ponds were estimated by using both mark–recapture and an electrofishing catch-per-effort (CPE) model, and these estimates were compared to actual densities of largemouth bass obtained after draining the pond. Mark–recapture underestimated populations of largemouth bass in 11 of 13 ponds. Error in mark–recapture estimation of numbers of largemouth bass decreased as the percentage of the population that was marked increased. Population estimates that used a previously published electrofishing CPE model underestimated population densities of largemouth bass obtained by pond draining, with errors ranging from 62.9 to 89.4%. Electrofishing CPE was significantly ($P < 0.05$) correlated with population density of largemouth bass but was not correlated with conductivity, turbidity, or plant biomass ($P > 0.05$ for all). A model to predict density of largemouth bass longer than 199 mm TL in ponds was developed by regressing actual population density against electrofishing CPE.

Fisheries biologists need accurate and cost-effective techniques for estimating densities of largemouth bass *Micropterus salmoides* if they are to effectively manage largemouth bass populations for sportfishing (Van Den Avyle 1993; Miranda et al. 1996). Historically, biologists have used techniques such as mark–recapture, catch depletion, and cove sampling with rotenone to estimate fish population density (Lagler 1972; Reynolds 1983; Van Den Avyle 1993). Several models have been proposed to predict population density of largemouth bass from electrofishing catch per effort (CPE; Hall 1986; Coble 1992; McInerny and Degan 1993; Hill and Willis 1994). These models are based on correlations between electrofishing CPE and population density estimated by using mark–recapture techniques. Because mark–recapture studies may be biased toward underestimating population densities (Robson and Regier 1964; Swingle et al. 1966; Grinstead and Wright 1973), CPE models based on mark–recapture estimates may underestimate population densities of largemouth bass. No study has tested the ability of these CPE models to predict actual densities of largemouth bass determined after lake draining. The objective of this study was to estimate population densities of largemouth bass by using the Peterson mark–recapture technique (Ricker 1975; Van Den Avyle 1993) and the electrofishing CPE model of Coble (1992) and to compare these estimates to actual population densities obtained after pond draining.

Methods

The study was conducted in 14 ponds at the Eagle Mountain Fish Hatchery, Fort Worth, Texas. The earthen ponds were filled and maintained with water from Eagle Mountain Lake, a eutrophic reservoir. Ponds ranged from 0.15 to 0.58 ha and had a maximum depth of 1.2 m. Ponds were stocked in 1990–1991 as part of an experiment examining the effects of two species of fish, common carp *Cyprinus carpio* and gizzard shad *Dorosoma cepedianum*, on water quality and centrarchid sport fish populations. All ponds were stocked with fingerling largemouth bass (123 fish/ha), fingerling bluegill *Lepomis macrochirus* (1,235 fish/ha), and triploid grass carp *Ctenopharyngodon idella* (25 fish/ha) that were 200–250 mm total length (TL). Six of the 14 ponds were also stocked with fingerling common carp (1,235 fish/ha) and adult gizzard shad (35 fish/ha).

Water temperature, conductivity, and turbidity were measured before electrofishing began. Water temperature and conductivity (μS/cm) were measured with a YSI model 33 conductivity meter approximately 0.5 m below the surface. Water samples for analysis of turbidity were collected near the deepest area of each pond with a 2-m-long polyvinyl chloride tube sampler (4-cm inside diameter) with a manually operated valve on the bottom. Turbidity (in nephelometric turbidity

[1] To whom correspondence should be addressed.

units, NTU) was analyzed with a Hach model 2100A turbidimeter.

Population densities of largemouth bass longer than 199 mm TL in each pond were estimated by using single-census Peterson-type mark–recapture (Ricker 1975), predicted with the electrofishing CPE-based model of Coble (1992), and determined with direct census after the pond was drained. For Peterson estimates, largemouth bass were marked after capture by angling and one night of electrofishing. From May to June 1995, before electrofishing, each pond was fished by anglers one or two times with artificial lures. Captured fish were measured, marked with a hole punch in the anal fin, and returned to the ponds. From 18 May to 15 June 1995, all ponds were electrofished on two separate nights, beginning 1 h after sunset. Time between nights ranged from 2 to 8 d. We used a Smith-Root GPP 5.0 pulsed DC unit with two Smith-Root front anode array booms mounted in a 4.3-m aluminum johnboat. The boat hull served as the cathode. All ponds were electrofished with a 60-Hz pulse rate, with an output between 4 and 5 A on the low-voltage setting (0–500 V). Fish were collected by a single dipper using a 5-mm-mesh dip net. To reduce crew sampling variability, the dipper and boat driver remained the same throughout the study (Hardin and Connor 1992). The entire perimeter and a transect across the center of each pond were electrofished both nights, for a combined effort ranging from 17.2 to 25.3 min/pond. The CPE was calculated by dividing the total number of largemouth bass collected by the total number of minutes of electrofishing from both nights. All fish were dipped, but when two or more species were simultaneously stunned, largemouth bass were given first collection priority. Fish were held in a solution of salt–quinaldine tranquilizer, measured, marked in the soft portion of the dorsal fin with a hole punch, checked for previous marks, and returned to the pond. Marked fish were not recorded for pond 14; therefore, this pond could not be used in the mark–recapture estimates, but it was used to test the CPE model of Coble (1992).

Mark–recapture estimates of population size were calculated by Bailey's modification of the Peterson method (Van Den Avyle 1993) with the equation

$$N_e = M(C + 1)/(R + 1),$$

where N_e is the estimated population, M is the total number of marked fish in the population, C is the total number of fish collected while sampling for recaptures, and R is the number of recaptures collected. Recaptures for Peterson estimates were collected on the second night of electrofishing. The marked population consisted of the samples collected by angling and during the first night of electrofishing. Percent of population marked was calculated by dividing the total number of largemouth bass marked by the number of largemouth bass recovered after pond draining. Percentage errors for the Peterson estimates were calculated by dividing the difference between actual density of largemouth bass and estimated densities by the actual density. According to Robson and Regier (1964), mark–recapture estimates may be biased toward underestimating population density if the product of $M \times C$ is less than $4N$. To address potential bias in the mark–recapture estimates in our study, we computed the value $M \times C/N_a$, where N_a was the actual number of largemouth bass determined after pond draining.

Population densities were predicted from the electrofishing CPE model of Coble (1992) by using the equation

$$\log D = 1.1641 \log(\text{CPH}) - 0.4516,$$

where D is density of largemouth bass longer than 199 mm TL (number/ha) and CPH is number of largemouth bass caught per hour of electrofishing. Percentage errors for the CPE model predictions were calculated by dividing the difference between actual density of largemouth bass and predicted densities by the actual density.

A complete census of largemouth bass longer than 199 mm TL was conducted after each pond was drained, 4–23 d after the second night of electrofishing. Ponds were drained from 6 June to 21 June 1995 by opening a valved pipe (20.3-cm inside diameter) to draw water and fish into a concrete fish collection box located in the deepest area of the pond.

Biomass of aquatic macrophytes and filamentous algae were estimated during pond draining. Ten vegetation samples were taken per pond along a line transect running from near the water inflow area to the opposite side of the pond. The first sample was taken 0.5 m off shore, and nine other samples were taken at randomly selected distances along the transect. At each sample site, all vegetation above the sediment surface was removed from an area 50 cm × 50 cm. Vegetation samples were placed in nylon mesh bags and stored in water until sorted by species. Plant specimens were blot-

TABLE 1.—Characteristics and fish-stocking treatment for 14 ponds at Eagle Mountain Hatchery, Fort Worth, Texas. Fish-stocking treatments were bluegill (BG), common carp (CC), gizzard shad (GS), and largemouth bass (LMB).

Pond	Surface area (ha)	Fish-stocking treatment	Conductivity (μS/cm)	Turbidity (NTU[a])	Plant biomass (g/m²)
1	0.18	BG, LMB	450	4.5	150.0
2	0.28	BG, LMB	555	3.0	240.5
3	0.22	BG, CC, GS, LMB	640	17.0	0.0
4	0.31	BG, LMB	428	4.5	326.8
5	0.34	BG, LMB	370	8.0	178.3
6	0.35	BG, CC, GS, LMB	364	10.0	336.3
7	0.49	BG, CC, GS, LMB	392	34.0	241.6
8	0.49	BG, LMB	388	4.0	135.5
9	0.48	BG, CC, GS, LMB	460	24.5	0.0
10	0.58	BG, LMB	468	8.0	73.8
11	0.15	BG, CC, GS, LMB	361	6.0	209.6
12	0.33	BG, LMB	486	2.5	108.4
13	0.38	BG, LMB	387	6.0	240.6
14	0.30	BG, CC, GS, LMB	536	27.5	0.0

[a] Nephelometric turbidity units.

ted with paper towels, sun-dried, and weighed to the nearest gram.

The data set was analyzed by linear regression analysis with SYSTAT (Wilkinson 1992). Regressions were performed between Peterson percent error and the percent of largemouth bass marked. Also, electrofishing CPE was regressed against actual population density of largemouth bass, conductivity, turbidity, and plant biomass (all species combined). Statistical significance was determined at $P < 0.05$. A model to predict density of largemouth bass in ponds was developed by regressing actual population density against electrofishing CPE.

Results

During electrofishing, pond water temperatures ranged from 26 to 28°C, and conductivity ranged from 361 to 640 μS/cm (Table 1). Turbidity ranged from 25 to 34.0 NTU, with highest turbidities in ponds stocked with common carp and gizzard shad. Dry plant biomass ranged from 0.0 to 336.3 g/m^2. Abundant plant taxa were naiads *Najas* spp., Eurasian water milfoil *Myriophyllum spicatum*, pondweeds *Potamogeton* spp., American lotus *Nelumbo lutea*, muskgrasses *Chara* spp., coontail *Ceratophyllum demersum*, grasses (Graminae), and unidentified filamentous algae.

The Peterson mark–recapture method underestimated densities of largemouth bass in 11 of the 13 ponds (Figure 1A; Table 2). Percent error between Peterson estimates and actual numbers of largemouth bass recovered ranged from 1.2 to 100%, with an average error of 30.0% (Table 2). Error of Peterson estimates decreased as the percentage of the population marked increased (Figure 1B). In 10 of the 13 ponds, $M \times C/N$ was less than 4 (Table 2). Robson and Regier (1964) suggested that mark–recapture estimates based on data where the product of $M \times C$ is less than $4 \times N$ will be negatively biased toward underestimating the population density and not valid for use in estimates of population density.

Electrofishing CPE ranged from 0.0 to 2.2 largemouth bass/min (Table 3). Use of our CPE data in the model of Coble (1992) underestimated densities of largemouth bass in all ponds (Table 3). Percent error of CPE–model estimates versus number of largemouth bass recovered at draining ranged from 62.9 to 89.4%, with an average error of 79.6% (Table 3).

We also examined the relationship between electrofishing CPE for largemouth bass and variables such as actual fish density, conductivity, turbidity, and plant biomass. Stepwise regression analysis showed that CPE was a linear function of actual population density of largemouth bass: $Y = 0.006X - 0.069$ ($r^2 = 0.661$, $P < 0.001$), where Y equals electrofishing CPE (number/min) and X equals largemouth bass population density (number/ha) (Figure 2). The CPE was not significantly correlated with conductivity, turbidity, and plant biomass ($P > 0.05$ for all).

A new predictive model was generated by plotting actual densities of largemouth bass as a function of electrofishing CPE (Figure 3). Regression analysis of largemouth bass population density versus electrofishing CPE yielded the following model: $Y = 181.000X + 59.635$ ($r^2 = 0.92$, $P < 0.001$), where Y equals largemouth bass population density (number/ha) and X equals electrofishing CPE (number/min).

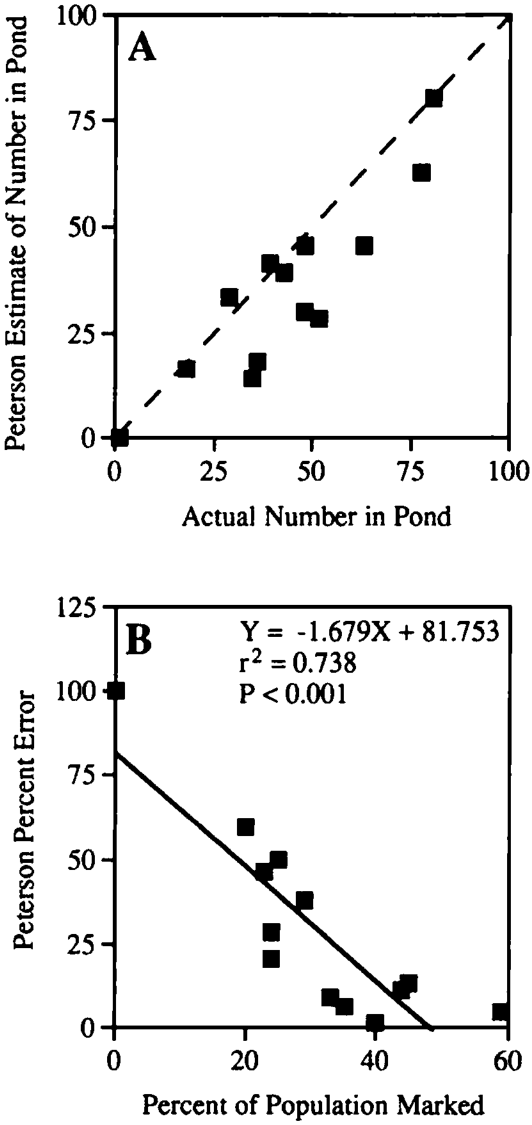

FIGURE 1.—(A) Comparison of numbers of largemouth bass longer than 199 mm total length estimated by the Peterson mark–recapture method to actual numbers determined by draining each pond. (B) Relationship between percentage error of Peterson method and percent of actual population marked.

Discussion

Our study found that the CPE model of Coble (1992) underestimated population densities in the ponds. The CPE model was based on data from Hall's (1986) mark–recapture studies of 12 Ohio lakes that ranged in size from 2.1 to 1,195 ha and Coble's (1992) mark–recapture study of a 16-ha Wisconsin lake. We postulate that Coble's model underestimated populations of largemouth bass in our ponds, in part, because the model was based on correlations of CPE and densities of largemouth bass estimated by mark–recapture. Our study confirmed the results of other studies (Swingle et al. 1966; Grinstead and Wright 1973) which have found that mark–recapture studies may be biased toward underestimation of populations of largemouth bass, especially if the numbers of marked fish and collected fish are small relative to the total number of fish in the population (Robson and Regier 1964).

Other differences in our study and the electrofishing surveys used to develop the CPE model of Coble (1992), such as temperature and lake size, may also account for the inability of Coble's (1992) model to predict the density of largemouth bass in the ponds, but we have little information about the role of these factors in CPE models. Our study was conducted at temperatures ranging from 26 to 28°C; some of the electrofishing data used in the model of Coble (1992) were from electrofishing surveys conducted by Hall (1986) at temperatures ranging from 7 to 25°C. Carline et al. (1984) found a seasonal change in vulnerability of largemouth bass to electrofishing gear that was probably related to a shift in habitat usage with change in temperature. The ponds in our study ranged from 0.15 to 0.58 ha with a maximum depth of 1.2 m, allowing us to electrofish them more efficiently than the larger systems studied by Hall (1986) and Coble (1992).

Several factors have been found to influence electrofishing CPE, including fish population density, conductivity, turbidity, and vegetation density. Electrofishing CPE has been shown to be closely related to fish population density in many studies (Sanderson 1960; Swingle et al. 1966; Grinstead and Wright 1973; Simpson 1978; Serns 1982, 1983; Hall 1986; Gabelhouse 1987; Coble 1992; Buynak and Mitchell 1993; McInerny and Degan 1993; Hill and Willis 1994) and this relationship is the basis for CPE models (Hall 1986; Coble 1992; McInerny and Degan 1993; Hill and Willis 1994). Hill and Willis (1994) stated that conductivity significantly affected CPE of AC electrofishing but not pulsed DC electrofishing. Electrofishing catch rates have been shown to increase with increased turbidity (Kirkland 1965; Simpson 1978). However, Dewey (1992) stated that dipping of stunned fish is less effective in turbid water. Bain and Boltz (1992) detected no decrease in largemouth bass catch rates before and after macrophyte eradication with herbicides. In

TABLE 2.—Population statistics and number of largemouth bass longer than 199 mm total length marked, collected, and recaptured in 13 ponds at Eagle Mountain Hatchery. Estimates were made according to the Peterson equation. The Peterson estimate was considered biased when $M \times C/N_a$ was less than 4.

Pond	Number of fish: Marked (M)	Number of fish: Collected (C)	Number of fish: Recaptured (R)	Peterson estimate of number in pond	Actual number recovered from pond (N_a)	Percent error of Peterson estimate	Percent of population marked	Test for bias ($M \times C/N_a$)
1	14	14	6	30	48	37.5	29	4.1
2	32	29	11	80	81	1.2	40	11.5
3	14	10	3	39	43	9.3	33	3.3
4	15	11	3	45	63	28.6	24	2.7
5	17	7	2	45	48	6.3	35	2.5
6	13	4	1	33	29	13.8	45	1.8
7	7	1	0	14	35	60.0	20	0.2
8	23	8	4	41	39	5.1	59	4.7
9	19	12	3	62	78	20.5	24	2.9
10	0	0	0	0	1	100.0	0	0
11	8	3	1	16	18	11.1	44	1.3
12	12	6	2	28	52	46.2	23	1.4
13	9	5	2	18	36	50.0	25	1.3
Mean						30.0		

our study, stepwise regression found that electrofishing CPE was a linear function of population density of largemouth bass but was not significantly correlated with conductivity, turbidity, or plant biomass. However, the ponds in our study were small and shallow; therefore, stunned fish had little chance for escape and variables such as turbidity and plant biomass may have been less important than observed in previous studies.

We propose a new model to estimate population densities of largemouth bass in ponds based on the relationship between electrofishing CPE and actual population density determined by draining of the 14 ponds. By development of a model from correlations between electrofishing CPE and actual population density, not estimated population density, we have attempted to avoid the negative bias that may be associated with mark–recapture estimates. In addition to being the sole method of population estimation, one possible use of the CPE

TABLE 3.—Electrofishing effort (total of both dates), number of largemouth bass longer than 199 mm total length collected, catch per effort (CPE), and density statistics. Model estimates were according to Coble (1992), and actual densities were determined by draining ponds and counting fish.

Pond	Electrofishing effort (min)	Number of fish collected	CPE (number/min)	Model estimate of fish density	Actual fish density	Model percent error
1	24.0	27	1.13	47.9	272	82.4
2	24.5	54	2.20	104.0	289	64.0
3	22.7	19	0.84	33.9	195	82.6
4	23.6	14	0.59	22.5	203	88.9
5	21.5	16	0.74	29.3	141	79.2
6	19.7	8	0.41	14.7	83	82.3
7	17.4	4	0.23	7.5	71	89.4
8	19.0	21	1.10	46.4	125	62.9
9	20.6	26	1.26	54.4	163	66.6
10	20.0	0	0.00		2	
11	17.2	8	0.47	17.2	120	85.7
12	18.9	13	0.69	27.0	158	82.9
13	19.1	8	0.42	15.1	95	84.1
14	25.3	22	0.87	35.3	210	83.2
Mean						79.6

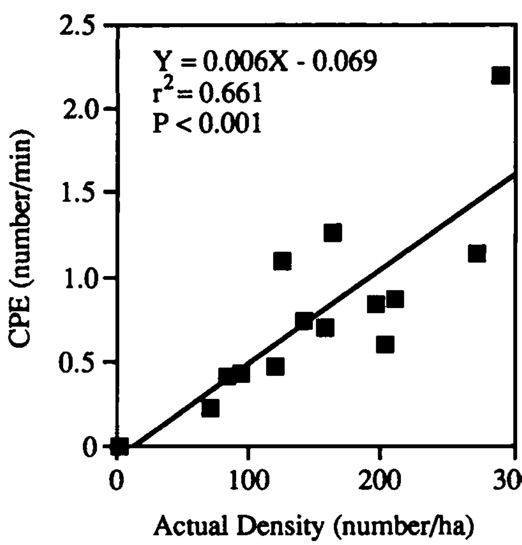

FIGURE 2.—Relationship between electrofishing catch per effort (CPE) for largemouth bass longer than 199 mm total length and actual density determined after draining each pond.

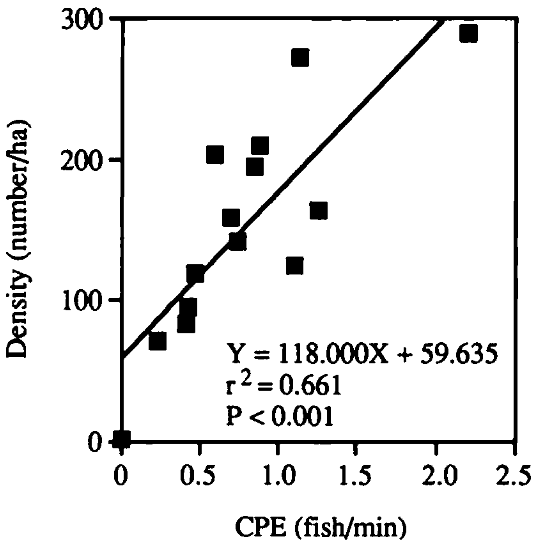

FIGURE 3.—Relationship between actual density of largemouth bass longer than 199 mm total length determined after draining each pond and electrofishing catch per effort (CPE, number/min).

model may be to help identify the number of fish that need to be marked during a mark–recapture study. As we found in the pond study, the accuracy of mark–recapture estimates improved as percentage of the population marked increased (Robson and Regier 1964; Lagler 1972; Van Den Avyle 1993). In order to accurately estimate fish population density by mark–recapture, investigators must first have some idea of the magnitude of the population density to know approximately how many fish must be marked to conduct an accurate mark–recapture study (Robson and Regier 1964). Until more research is conducted on the relative merits of the two methods, we recommend that the population density of largemouth bass in ponds be estimated by using a combination of electrofishing CPE and mark–recapture methods.

Acknowledgments

We thank the Tarrant County Water Control and Improvement District Number One for use of the Eagle Mountain Fish Hatchery, the Texas Parks and Wildlife Department for use of equipment and Eric Dibble, Sherry Harrel, Steven George, Kristina Stewart, Stacy Molahan, Jeff Gilroy, Mark Lauden, Wes Nowlin, Corbett Redden, Tasha Metz, Clell Guest, and John Horner for assistance. Reviews by Michael McInerny and Laurence Connor improved the manuscript. This research was supported by a grant to R. W. Drenner from the Waterways Experiment Station, U.S. Army Corps of Engineers.

References

Bain, M. B., and S. E. Boltz. 1992. Effect of aquatic plant control on the microdistribution and population characteristics of largemouth bass. Transactions of the American Fisheries Society 121:94–103.

Buynak, G. L., and B. Mitchell. 1993. Electrofishing catch per effort as a predictor of largemouth bass abundance and angler catch in Taylorsville Lake, Kentucky. North American Journal of Fisheries Management 13:630–633.

Carline, R. F., B. L. Johnson, and T. J. Hall. 1984. Estimation and interpretation of proportional stock density for fish populations in Ohio impoundments. North American Journal of Fisheries Management 4:139–154.

Coble, D. W. 1992. Predicting population density of largemouth bass from electrofishing catch per effort. North American Journal of Fisheries Management 12:650-652.

Dewey, M. R. 1992. Effectiveness of a drop net, a pop net, and an electrofishing frame for collecting quantitative samples of juvenile fishes in vegetation. North American Journal of Fisheries Management 12:808–813.

Gabelhouse, D. W. 1987. Responses of largemouth bass and bluegills to removal of surplus largemouth bass from a Kansas pond. North American Journal of Fisheries Management 7:81–90.

Grinstead, B. G., and G. L. Wright. 1973. Estimation of black bass, *Micropterus* spp., population in Eufaula Reservoir, Oklahoma, with discussion of techniques. Proceedings of the Oklahoma Academy of Science 53:48–52.

Hall, T. J. 1986. Electrofishing catch per hour as an indicator of largemouth bass density in Ohio impoundments. North American Journal of Fisheries Management 6:397–400.

Hardin, S., and L. L. Connor. 1992. Variability of electrofishing crew efficiency, and sampling requirements for estimating reliable catch rates. North American Journal of Fisheries Management 12: 612–617.

Hill, T. D., and D. W. Willis. 1994. Influence of water conductivity on pulsed AC and pulsed DC electrofishing catch rates for largemouth bass. North American Journal of Fisheries Management 14:202–207.

Kirkland, L. 1965. A tagging experiment on spotted and largemouth bass using an electric shocker and the Peterson disk tag. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 16(1962):424–432.

Lagler, K. F. 1972. Freshwater fishery biology. Brown, Dubuque, Iowa.

McInerny, M. C., and D. J. Degan. 1993. Electrofishing catch rates as an index of largemouth bass population density in two large reservoirs. North American Journal of Fisheries Management 13:223–228.

Miranda, L. E., W. D. Hubbard, S. Sangare, and T. Holman. 1996. Optimizing electrofishing sample duration for estimating relative abundance of largemouth bass in reservoirs. North American Journal of Fisheries Management 16:324–331.

Reynolds, J. B. 1983. Electrofishing. Pages 147–163 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Robson, D. S., and H. A. Regier. 1964. Sample size in Peterson mark–recapture experiments. Transactions of the American Fisheries Society 93:215–226.

Sanderson, A. E. 1960. Results of sampling the fish population of an 88-acre pond by electrical, chemical, and mechanical methods. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 14(1960):185–198.

Serns, S. L. 1982. Relationship of walleye fingerling density and electrofishing catch per effort in northern Wisconsin lakes. North American Journal of Fisheries Management 2:38–44.

Serns, S. L. 1983. Relationship between electrofishing catch per effort and density of walleye fingerlings. North American Journal of Fisheries Management 3:451–452.

Simpson, D. E. 1978. Evaluation of electrofishing efficiency for largemouth bass and bluegill populations. Master's thesis. University of Missouri, Columbia.

Swingle, W. E., R. O. Smitherman, and S. L. Spencer. 1966. Estimation of bass numbers in a farm pond prior to draining with electro-shocking and angling. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 19(1965):246–253.

Van Den Avyle, M. J. 1993. Dynamics of exploited fish populations. Pages 105–134 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Wilkinson, 1992. SYSTAT 5 user's manual, SYSTAT version 5.2. SYSTAT, Evanston, Illinois.